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Katou et al.

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(54) **INTERNAL COMBUSTION ENGINE**

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(51) **Int. Cl.**

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F02D 41/34	(2006.01)
F02D 41/40	(2006.01)
F02D 41/00	(2006.01)
F02D 13/02	(2006.01)

(52) **U.S. Cl.**

CPC ***F02D 41/3094*** (2013.01); ***F02D 41/025*** (2013.01); ***F02D 41/345*** (2013.01); ***F02D 41/401*** (2013.01); *F02D 13/0242* (2013.01); *F02D 13/0265* (2013.01); *F02D 41/006* (2013.01); *F02D 2041/001* (2013.01); *F02D 2200/0804* (2013.01); *Y02T 10/26* (2013.01); *Y02T 10/44* (2013.01)

(58) **Field of Classification Search**

USPC 60/272–324

See application file for complete search history.

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(57) **ABSTRACT**

An internal combustion engine includes fuel injection valves and an ECU. In the internal combustion unit, predetermined injection is performed when the bed temperature of a catalyst is lower that a predetermined temperature. In the predetermined injection, fuel is injected from a first fuel injection valve, from among the fuel injection valves, within the valve opening period of an intake valve, and fuel is injected from a second fuel injection valve, from among the fuel injection valves, within the valve opening period of an exhaust valve. In the internal combustion engine, a first injection amount is specifically injected from the first fuel injection valve in the predetermined injection.

4 Claims, 5 Drawing Sheets

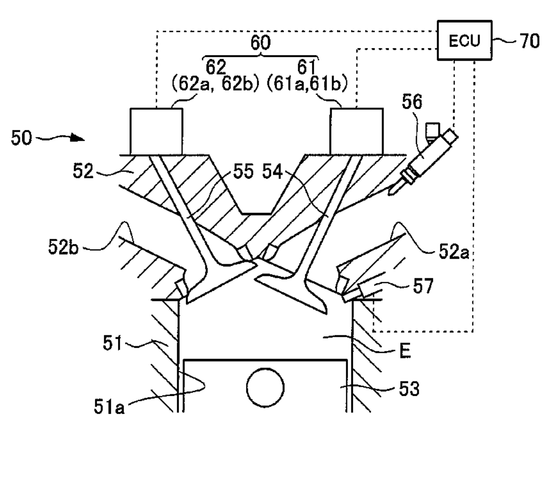

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FIG. 1

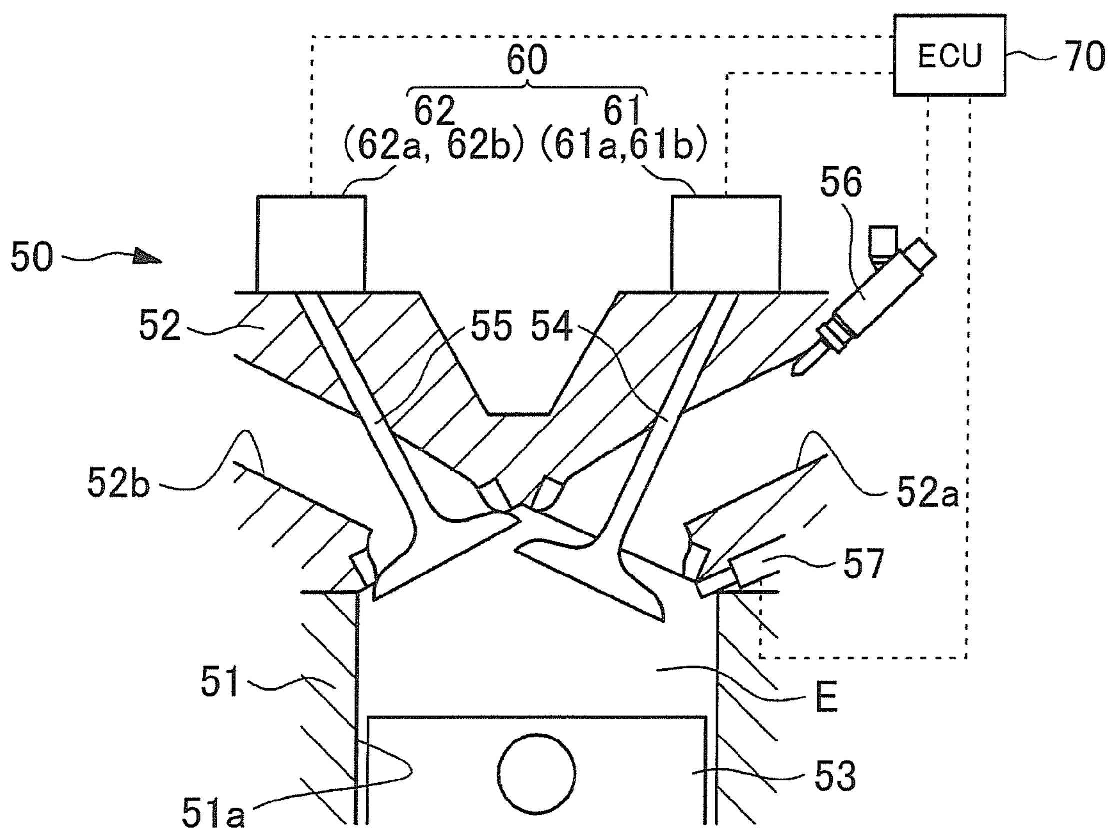


FIG. 2

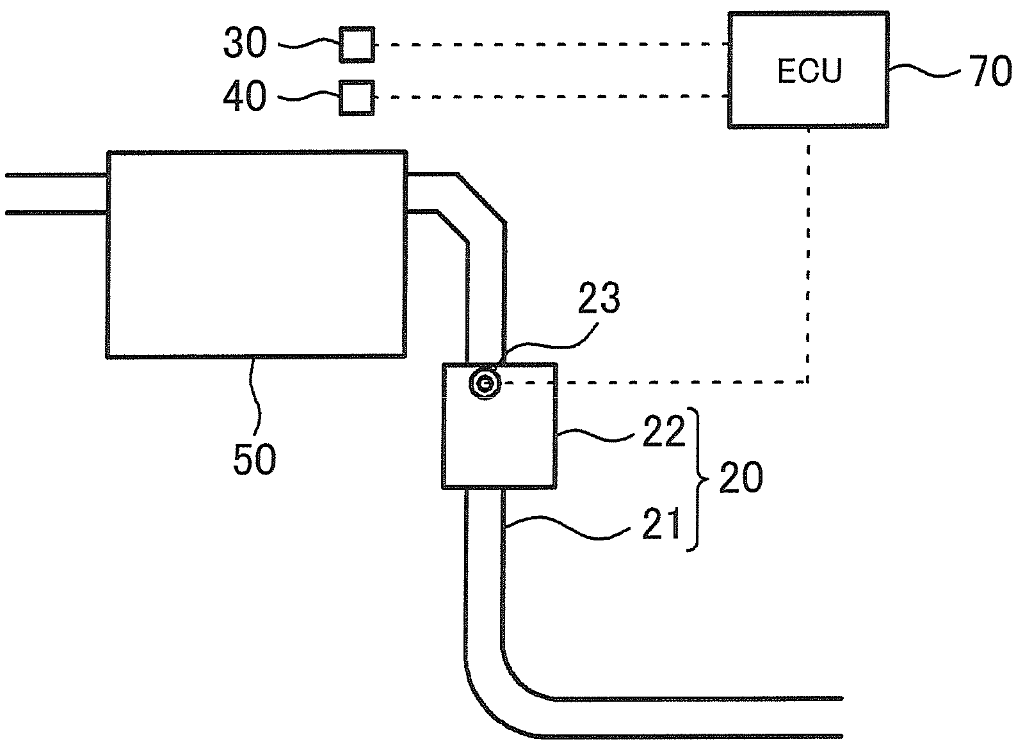


FIG. 3

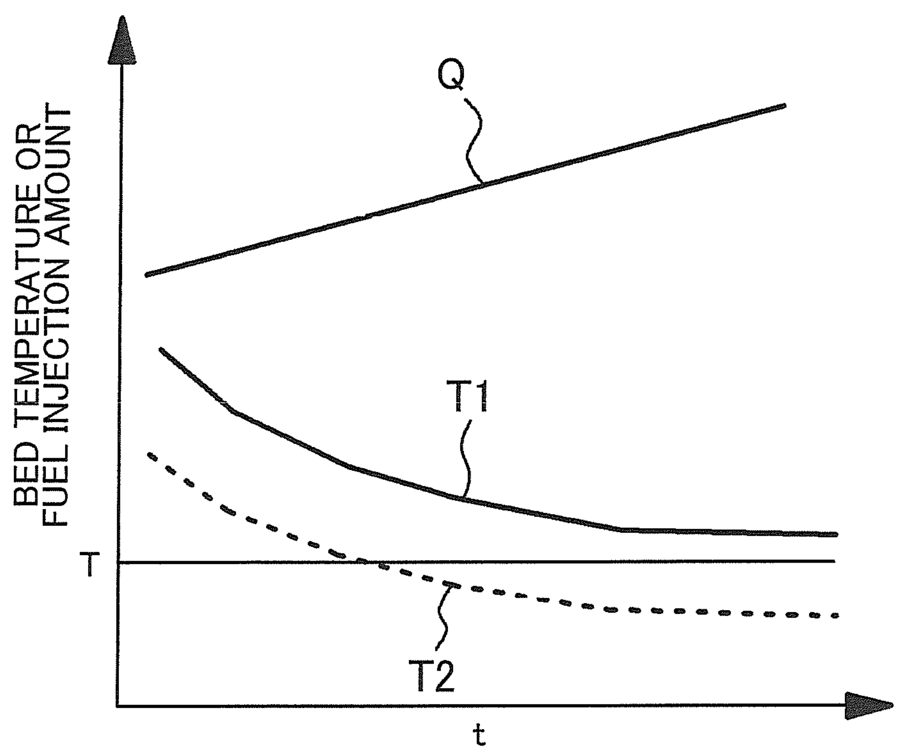


FIG. 4

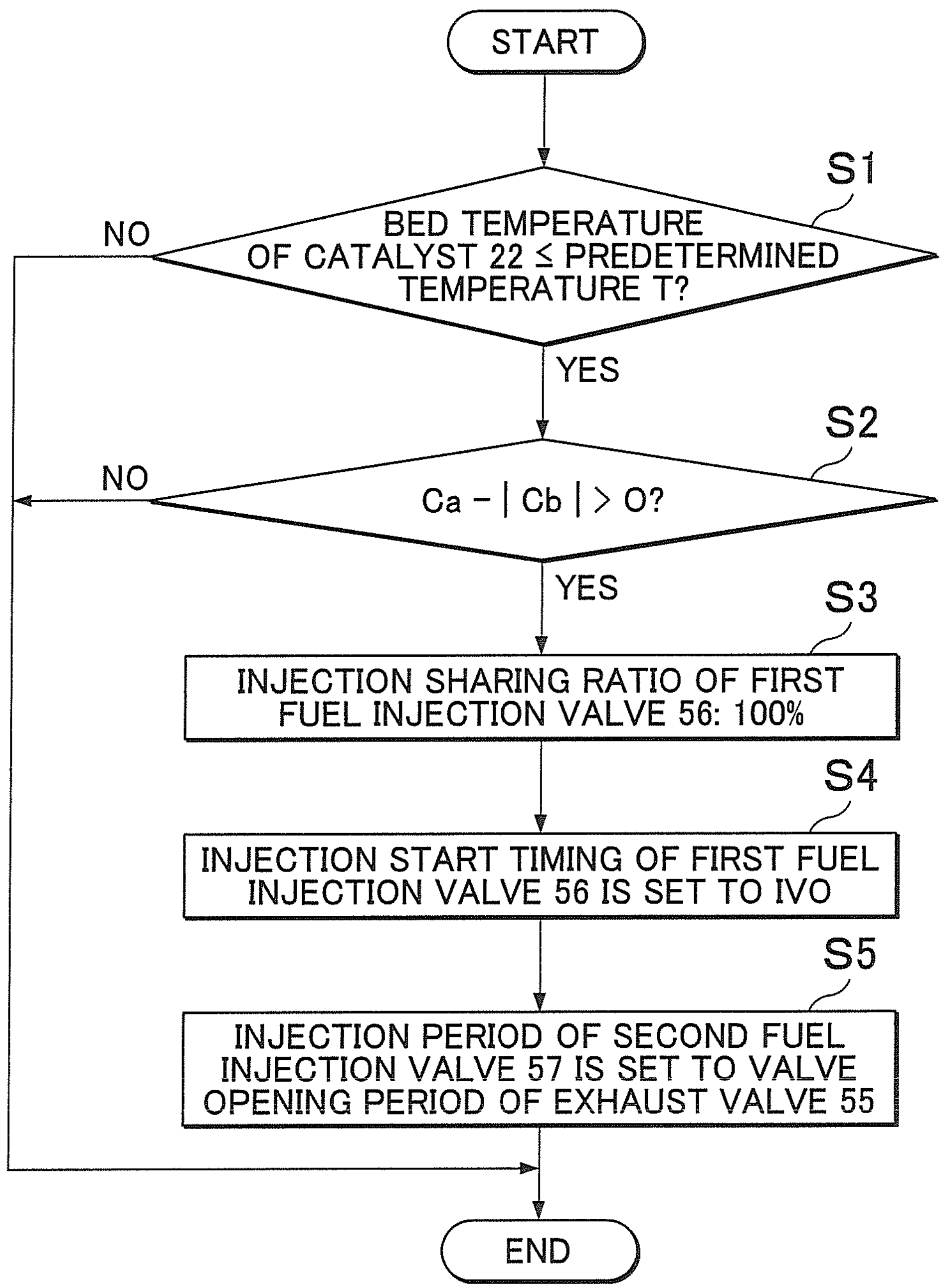
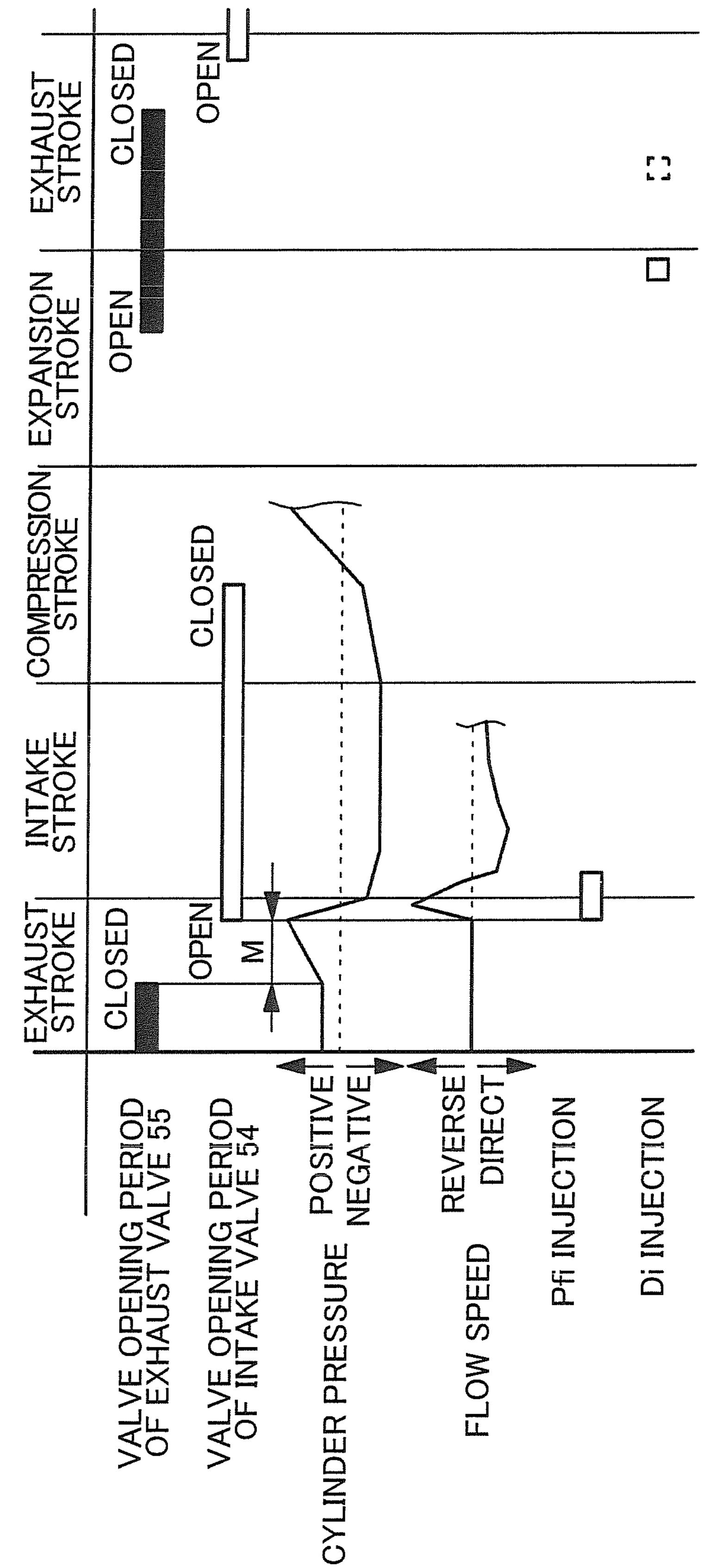

START
S1
BED TEMPERATURE OF CATALYST 22 ≤ PREDETERMINED TEMPERATURE T?
NO
YES
S2
Ca − | Cb | > O?
NO
YES
S3
INJECTION SHARING RATIO OF FIRST FUEL INJECTION VALVE 56: 100%
S4
INJECTION START TIMING OF FIRST FUEL INJECTION VALVE 56 IS SET TO IVO
S5
INJECTION PERIOD OF SECOND FUEL INJECTION VALVE 57 IS SET TO VALVE OPENING PERIOD OF EXHAUST VALVE 55
END

FIG. 5


EXHAUST STROKE
INTAKE STROKE
COMPRESSION STROKE
EXPANSION STROKE
EXHAUST STROKE
VALVE OPENING PERIOD OF EXHAUST VALVE 55
VALVE OPENING PERIOD OF INTAKE VALVE 54
CYLINDER PRESSURE
POSITIVE
NEGATIVE
FLOW SPEED
REVERSE
DIRECT
Pfi INJECTION
Di INJECTION
CLOSED
OPEN
M
OPEN
CLOSED
OPEN
CLOSED
CLOSED
OPEN

INTERNAL COMBUSTION ENGINE

INCORPORATION BY REFERENCE

The disclosure of Japanese Patent Application No. 2013-084226 filed on Apr. 12, 2013 including the specification, drawings and abstract is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to an internal combustion engine.

2. Description of Related Art

There is available an internal combustion engine that includes a first injection unit that injects fuel into an intake passage communicating with a combustion chamber and a second injection unit that injects fuel into the combustion chamber (see, for example, Japanese Patent Application Publication No. 2007-127059 (JP 2007-127059 A). Other techniques that can be considered to be relating to the invention are disclosed, for example, in Japanese Patent Application Publication No. 2010-265814 (JP 2010-265814 A), Japanese Patent Application Publication No. 2008-57380 (JP 2008-57380 A), Japanese Patent Application Publication No. 2005-201083 (JP 2005-201083 A), and Japanese Patent Application Publication No. JP 2011-241714 (JP 2011-241714 A).

JP 2010-265814 A discloses the technique for promoting the atomization of the fuel injected form a port injection injector by the blowback of gas into an intake port. JP 2008-57380 A discloses the technique for injecting fuel in an exhaust stroke when the engine is started. JP 2005-201083 A discloses the technique for removing the deposit building up in the nozzle of a cylinder injection valve by performing fuel injection only with the cylinder injection valve for a predetermined period even in an operation region in which fuel injection is performed by an intake passage injection valve. JP 2011-241714 A discloses the technique for injecting a small amount of fuel from a cylinder injection valve within a minus overlap period and injecting fuel for output control from a port injection valve in the intake stroke.

In the internal combustion engine including the first and second injection units, the required injection amount is sometimes less than the sum total of the lowest injection amounts that can be injected by the injection valves. In such cases, where an attempt is made to inject fuel from both injection units, the amount of the supplied fuel becomes larger than the required injection amount and the fuel-air mixture becomes rich, thereby destabilizing the combustion. To resolve this problem, the required injection amount can be injected, for example, from the first injection unit, from among the first and second injection units. As a result, the fuel is supplied under a low pressure and the injection amount is easily controlled, thereby making it possible to obtain stable combustion.

However, in such cases, the fuel is not injected from the second injection unit. Therefore, in such cases, deposits can appear and build up in the nozzle of the second injection unit. Meanwhile, in order to clean the exhaust gas in the internal combustion engine, it is desirable that warm-up of a catalyst be promoted in the case in which the bed temperature of the catalyst is lower than a predetermined temperature (for example, activity temperature).

SUMMARY OF THE INVENTION

It is an object of the invention to provide an internal combustion engine in which the deposit build-up in the nozzle of

the second injection unit can be advantageously prevented or inhibited by injecting the fuel rationally from the second injection unit in addition to the injection from the first injection unit even when it is desired to inject the required injection amount from the first injection unit.

According to an aspect of the invention, an internal combustion engine includes: a first injection unit injecting fuel into an intake passage communicating with a combustion chamber; a second injection unit injecting fuel into the combustion chamber; and an intake valve and an exhaust valve arranged with respect to the combustion chamber, wherein, when a bed temperature of a catalyst for purifying exhaust gas discharged from the combustion chamber is lower than a predetermined temperature, predetermined injection is performed in such a manner that fuel is injected from the first injection unit, from among the first and second injection units, within a valve opening period of the intake valve, and fuel is injected from the second injection unit, from among the first and second injection units, within a valve opening period of the exhaust valve.

The internal combustion engine according to the above-described aspect may be configured to further include a piston adjacent to the combustion chamber, and a valve train changing at least a valve closing timing of the exhaust valve, from among valve characteristics of the intake valve and the exhaust valve, wherein the predetermined injection is performed in a predetermined case and in a case in which the bed temperature of the catalyst is lower than a predetermined temperature, and the predetermined case is a case in which the valve train is in a state of closing the exhaust valve on an advance side with respect to the exhaust top dead center of the piston and forming a minus overlap between the intake valve and the exhaust valve.

According to the above-described aspect of the invention, the deposit build-up in the nozzle of the second injection unit can be advantageously prevented or inhibited by injecting the fuel rationally from the second injection unit in addition to the injection from the first injection unit even when it is desired to inject the required injection amount from the first injection unit.

BRIEF DESCRIPTION OF THE DRAWINGS

Features, advantages, and technical and industrial significance of exemplary embodiments of the invention will be described below with reference to the accompanying drawings, in which like numerals denote like elements, and wherein:

FIG. **1** is a schematic configuration diagram of an internal combustion engine;

FIG. **2** shows an exhaust system of the internal combustion engine;

FIG. **3** is an explanatory drawing of a second injection amount;

FIG. **4** shows by a flowchart an example of control operation; and

FIG. **5** shows an example of fuel injection performed by the internal combustion engine.

DETAILED DESCRIPTION OF EMBODIMENTS

An embodiment of the invention is described below with reference to the appended drawings.

FIG. **1** is a schematic configuration diagram of an internal combustion engine **50**. FIG. **2** illustrates an exhaust system **20** of the internal combustion engine **50**. The internal combustion engine **50** is provided with a cylinder block **51**, a cylinder head **52**, a piston **53**, an intake valve **54**, an exhaust valve **55**, a first fuel injection valve **56**, a second fuel injection valve **57**, a valve train **60**, and an ECU **70**.

A cylinder **51***a* is formed in the cylinder block **51**. The piston **53** is accommodated inside the cylinder **51***a*. The cylinder head **52** is fixed to the upper surface of the cylinder block **51**. A combustion chamber E is formed as a space bounded by the cylinder block **51**, the cylinder head **52**, and the piston **53**. The piston **53** is adjacent to the combustion chamber E.

An intake port **52***a* introducing intake air into the combustion chamber E, and an exhaust port **52***b* discharging gas from the combustion chamber E are formed in the cylinder head **52**. The intake valve **54** that opens and closes the intake port **52***a*, and the exhaust valve **55** that opens and closes the exhaust port **52***b* are also provided in the cylinder head **52**. The intake port **52***a* forms an intake passage. The intake passage communicates with the combustion chamber E.

The first and second fuel injection valves **56**, **57** are both provided in the cylinder head **52**. The first fuel injection valve **56** injects fuel into the intake passage formed by the intake port **52***a*. The second fuel injection valve **57** injects fuel into the combustion chamber E. The second fuel injection valve **57** is provided in a portion on the intake side, from among the intake side and exhaust side of the cylinder head **52**. The arrangement of the second fuel injection valve **57** is not necessarily limited thereto. The first fuel injection valve **56** corresponds to the first injection unit, and the second fuel injection valve **57** corresponds to the second injection unit.

The cylinder head **52** is provided with the valve train **60**. The valve train **60** is provided with an intake-side variable valve train **61** capable of changing the valve characteristics of the intake valve **54**, and an exhaust-side variable valve train **62** capable of changing the valve characteristics of the exhaust valve **55**. The valve characteristics include the valve opening timing, valve closing timing, lift amount, or a combination thereof (for example, the opening-closing timing, or the valve closing timing and the lift amount, or the valve opening timing, valve closing timing, and lift amount).

The intake-side variable valve train **61** is configured by an intake-side valve timing variable mechanism **61***a* changing the opening-closing timing of the intake valve **54**, and an intake-side lift amount variable mechanism **61***b* changing the operation angle (valve opening period) of the intake valve **54**. The exhaust-side variable valve train **62** is configured by an exhaust-side valve timing variable mechanism **62***a* changing the opening-closing timing of the exhaust valve **55**, and an exhaust-side lift amount variable mechanism **62***b* changing the operation angle of the exhaust valve **55**.

The valve timing variable mechanisms **61***a*, **62***a* are each specifically of a hydraulic drive system and configured to have an oil control unit that controls the transmission of oil pressure. The lift amount variable mechanisms **61***b*, **62***b* are each specifically of an electric system and have an electric actuator. The electric actuator is, for example, a control motor. The lift amount variable mechanisms **61***b*, **62***b* may be also of a hydraulic drive system, similarly to the respective valve timing variable mechanisms **61***a*, **62***a*.

The intake-side lift amount variable mechanism **61***b* is configured to change the valve opening timing of the intake valve **54** by changing the operation angle of the intake valve **54**. The intake-side lift amount variable mechanism **61***b* is specifically configured such that the valve opening timing of the intake valve **54** advances when the operation angle is enlarged, and the valve opening timing of the intake valve **54** lags when the operation angle is reduced. Even more specifically, the intake-side lift amount variable mechanism **61***b* is configured such that the valve closing timing of the intake valve **54** lags when the operation angle is enlarged, and the valve closing timing of the intake valve **54** advances when the operation angle is reduced.

The exhaust-side lift amount variable mechanism **62***b* is configured to change the valve closing timing of the exhaust valve **55** by changing the operation angle of the exhaust valve **55**. The exhaust-side lift amount variable mechanism **62***b* is specifically configured such that the valve closing timing of the exhaust valve **55** lags when the operation angle is enlarged, and the valve closing timing of the exhaust valve **55** advances when the operation angle is reduced. Even more specifically, the exhaust-side lift amount variable mechanism **62***b* is configured such that the valve opening timing of the exhaust valve **55** advances when the operation angle is enlarged, and the valve opening timing of the exhaust valve **55** lags when the operation angle is reduced.

The exhaust-side variable valve train **62** can change the valve closing timing of the exhaust valve **55** by changing the opening-closing timing of the exhaust valve **55** with the exhaust-side valve timing variable mechanism **62***a*. The exhaust-side variable valve train **62** can also change the valve closing timing of the exhaust valve **55** by changing the operation angle of the exhaust valve **55** with the exhaust-side lift amount variable mechanism **62***b*.

As a result of being provided with the exhaust-side variable valve train **62**, the valve train **60** can change at least the valve closing timing of the exhaust valve **55**, from among the valve characteristics of the intake valve **54** and the exhaust valve **55**. Such a valve train can be configured to include at least the exhaust-side variable valve train **62** from among the intake-side variable valve train **61** and the exhaust-side variable valve train **62**. The exhaust-side variable valve train **62** in such a valve train can be configured to include at least either of the exhaust-side valve timing variable mechanism **62***a* and the exhaust-side lift amount variable mechanism **62***b*. The valve train is not limited to those described hereinabove and may be another valve train that can change the valve closing timing of the exhaust valve **55**.

The exhaust system **20** is connected to the internal combustion engine **50**. The exhaust system **20** is provided with an exhaust pipe **21** and a catalyst **22**. The exhaust pipe **21** forms an exhaust passage. The exhaust passage communicates with the combustion chamber E. The catalyst **22** is provided so as to be introduced in the exhaust pipe **21** and cleans the exhaust gas discharged from the combustion chamber E. The catalyst **22** is specifically, for example, a three-way catalyst. The catalyst **22** is provided with an exhaust gas temperature sensor **23**.

The ECU **70** is an electronic control device. The valve train **60** (more specifically, oil control units and electric actuators of the variable valve trains **61**, **62**) is electrically connected as a control object to the ECU **70**. The exhaust gas temperature sensor **23**, a first sensor group **30** for detecting the operation state of the internal combustion engine **50**, or a second sensor group **40** for detecting the state of the valve train **60** is also electrically connected as a sensor switch.

The first sensor group **30** includes, for example, a crank angle sensor that can detect the revolution speed of the internal combustion engine **50**, an air flow meter that measures an intake air amount of the internal combustion engine **50**, an accelerator depression amount sensor issuing an acceleration request to the internal combustion engine **50**, and a water temperature sensor detecting the cooling water temperature of the internal combustion engine **50**. The second sensor group **40** includes, for example, sensors for detecting the valve opening timing and valve closing timing of the intake valve **54** and the exhaust valve **55**, and a sensor for detecting the set lift amount (or the set operation angle) of the intake valve **54** and the exhaust valve **55**. The set lift amount is, for example, a lift amount determined by the maximum lift amount.

For example, the below-described control unit, injection control unit, estimation unit, and determination unit are realized by a central processing unit (CPU) of the ECU **70** executing the processing while using, as necessary, the temporary storage area of a random access memory (RAM) on the basis of a program stored in a read only memory (ROM). Those configurations may be also individually realized for each feature, for example, by using a plurality of electronic control units.

The control unit controls the valve train **60**. The control unit controls the valve train **60**, for example, such that the exhaust valve **55** is closed on the advance side with respect to the exhaust top dead center of the piston **53** and such that a minus overlap is formed between the intake valve **54** and the exhaust valve **55**. The minus overlap is the overlap of the valve closing period between the intake valve **54** and the exhaust valve **55**, more specifically the overlap of the valve closing period formed from the valve closing timing of the exhaust valve **55** till the valve opening timing of the intake valve **54**. The control unit controls the valve train **60** in the above-described manner, for example, when the operation state of the internal combustion engine **50** is a high-temperature low-load state including a high-temperature idle period. The valve train **60** may be also understood as a configuration including the control unit.

The injection control unit controls fuel injection of the fuel injection valves **56**, **57**. The injection control unit controls the fuel injection valves **56**, **57** such that a predetermined injection I is performed when the bed temperature of the catalyst **22** is lower that a preset temperature T (in this case, equal to or lower than the predetermined temperature T). The predetermined temperature T is, for example, activity temperature of the catalyst **22**. In the predetermined injection I, the fuel is injected from the first fuel injection valve **56**, from among the fuel injection valves **56**, **57**, within the valve opening period of the intake valve **54**, and the fuel is injected from the second fuel injection valve **57**, from among the fuel injection valves **56**, **57**, within the valve opening period of the exhaust valve **55**. In the internal combustion engine **50**, the predetermined injection I is performed when the bed temperature of the catalyst **22** is lower than the predetermined temperature T on the basis of such control executed by the injection control unit.

The injection control unit controls the fuel injection valves **56**, **57** such that the predetermined injection I is performed in a predetermined case (A) in which the bed temperature of the catalyst **22** is lower than the predetermined temperature T. The predetermined case (A) is a case in which the valve train **60** is in a state of closing the exhaust valve **55** on the advance side with respect to the exhaust top dead center of the piston **53** and forming a minus overlap.

In the predetermined injection I, the injection control unit specifically controls the fuel injection valves **56**, **57** such that a first injection amount TAU is injected from the first fuel injection valve **56**, and a second injection amount Q is injected from the second fuel injection valve **57**. The first fuel injection amount TAU is the required injection amount, more specifically the injection amount required per cylinder of the internal combustion engine **50**. The first injection mount TAU is the injection amount corresponding to the required output. The second injection amount Q is an additional injection amount which is different from the first injection amount TAU and injected in addition to the first injection amount TAU.

Concerning the first injection amount TAU, the injection control unit sets the injection sharing ratio of the first injection amount TAU among the fuel injection valves **56**, **57**. Therefore, the first injection amount TAU can be more specifically defined as an injection amount for which the injection sharing ratio is set among the fuel injection valves **56**, **57**.

The injection control unit determines the injection sharing ratio, for example, such that the first injection amount TAU is injected from the first fuel injection valve **56**, from among the fuel injection valves **56**, **67**, in the predetermined case (A). Thus, the setting of the injection sharing ratio, as viewed from the first fuel injection valve **56** (referred to hereinbelow simply as the injection sharing ratio of the first fuel injection valve **56**), is taken as 100%. More specifically, in the predetermined injection I, the first fuel injection valve **56** injects the first injection amount TAU by determining such an injection sharing ratio.

FIG. **3** is an explanatory drawing showing the second injection amount Q. On the ordinate in FIG. **3**, the fuel injection amount is shown with respect to the second injection amount Q, and the bed temperature of the catalyst **22** is shown with respect to temperatures T**1**, T**2**. A period t required to restart the internal combustion engine **50** after the engine has been stopped is plotted on the abscissa. The temperature T**1** is the bed temperature of the catalyst **22** in the case in which fuel injection is performed from the second fuel injection valve **57** during idling immediately after the engine has been restarted. The temperature T**2** is the bed temperature of the catalyst **22** in the case in which no fuel injection is performed from the second fuel injection valve **57** during idling immediately after the engine has been restarted.

As shown in FIG. **3**, the temperatures T**1**, T**2** decrease as the period t is extended. It is also clear that where the period t is extended, the temperature T**2** decreases below a predetermined T, whereas the temperature T**1** is higher than the predetermined temperature T, regardless of the period t. This is because the bed temperature of the catalyst **22** is raised by the post-combustion of the fuel injected from the second fuel injection valve **57** during idling immediately after the internal combustion engine **50** has been restarted. Another reason is that the injection control unit changes the second injection mount Q so that the bed temperature of the catalyst **22** becomes higher than the preset temperature T.

More specifically, when the second injection amount Q is thus changed, the injection control unit changes the second injection amount Q according to the bed temperature of the catalyst **22**. Even more specifically, the injection control unit changes the second injection amount Q so that the second injection amount Q increases with the decrease in the bed temperature of the catalyst **22**. The second injection amount Q can be set in advance with map data according to the bed temperature of the catalyst **22**. The injection control unit may be also configured as a plurality of injection control units (for example, first and second injection control units) that differ, for example, in control contents.

Specifically in the predetermined injection I, the injection control unit controls the first fuel injection valve **56** such that the fuel injection is started from the first fuel injection valve **56** at the valve opening timing (IVO) of the intake valve **54**. In other words, in the predetermined injection I, the injection control unit synchronizes the fuel injection start timing of the first fuel injection valve **56** with the IVO. In the predetermined injection I, the injection control unit can inject the fuel from the second fuel injection valve **57** at least in either one stroke from among the expansion stroke and exhaust stroke.

The estimation unit estimates the bed temperature of the catalyst **22**. The estimation unit can estimate the bed temperature of the catalyst **22**, for example, by estimating the amount of heat received and released by the catalyst **22** on the basis of the intake air amount, exhaust temperature, and period t of the internal combustion engine **50**. The bed temperature of the catalyst **22** may be estimated, for example, on the basis of the cooling water temperature of the internal combustion engine **50**. Alternatively, the bed temperature of the catalyst **22** may be directly detected, for example, with a sensor.

The determination unit performs various types of determination. The determinations performed by the determination unit are explained in the explanation of the operation of the ECU **70** presented hereinbelow. The determination unit can be understood, for example, as a determination unit performing at least some of a plurality of different determinations. In this case the determination unit may be configured as a plurality of determination units (for example, first and second determination units) that differ, for example, in determination contents.

An example of the control operations performed by the ECU **70** is explained below by using a flowchart shown in FIG. **4**. In the ECU **70**, the bed temperature of the catalyst **22** is estimated and the second injection amount Q is changed separately from each other and at all times. The ECU **70** determines whether or not the bed temperature of the catalyst **22** is equal to or lower than the predetermined temperature T (step S**1**). Where a positive determination is made, the ECU **70** determines whether or not periods Ca, Cb fulfill the condition $Ca-|Cb|>0$ (whether or not a value obtained by subtracting the period Cb from the period Ca is greater than zero) (step S**2**).

The period Ca is a period between the valve closing timing of the exhaust valve **55** and the exhaust top dead center thereof. The period Cb is a period between the exhaust top dead center and the valve opening timing of the intake valve **54**. The period Ca is taken to be positive when the valve closing timing of the exhaust valve **55** and the exhaust top dead center arrive in the order of description, and the period Cb is taken to be positive when the exhaust top dead center and the valve opening timing of the intake valve **54** arrive in the order of description. When $Ca-|Cb|$ is greater than zero, it indicates a minus overlap amount. The valve opening timing of the intake valve **54** may be set, for example, to the advance side with respect to the exhaust top dead center.

In step S**2**, it is determined whether or not a state is assumed in which the exhaust valve **55** is closed on the advance side with respect to the exhaust top dead center and a minus overlap is formed. Therefore, where a positive determination is made in both step S**1** and step S**2**, it is determined that the predetermined case (A) is realized in which the bed temperature of the catalyst **22** is lower than the predetermined temperature T. Where a negative determination is made in step S**1** or step S**2**, the present flowchart is ended.

Where a positive determination is made in step S**2**, the ECU **70** sets the injection sharing ratio of the first fuel injection valve **56** to 100% (step S**3**). As a result, the injection amount of the first fuel injection valve **56** is set to the first injection amount TAU. After step S**3**, the ECU **70** synchronizes the injection start timing of the first fuel injection valve **56** with the IVO (step S**4**). Further, the fuel injection from the second fuel injection valve **57** is set to the valve opening period of the exhaust valve **55** (step S**5**). In step S**4**, the fuel injection from the first fuel injection valve **56** is simultaneously set to the valve opening period of the intake valve **54** by synchronizing the injection start timing of the first fuel injection valve **56** with the IVO. After step S**5**, the present flowchart is ended.

FIG. **5** shows an example of fuel injection performed by the internal combustion engine **50**. The cylinder pressure indicates the pressure in the combustion chamber E. The flow speed indicates the flow speed of gas in the intake port **52***a*. The direct flow indicates the flow from the intake port **52***a* to the combustion chamber E, and the reverse flow indicates the flow from the combustion chamber E to the intake port **52***a*. The Pfi injection indicates fuel injection from the first fuel injection valve **56**. The Di injection indicates fuel injection from the second fuel injection valve **57**. The period M indicates the minus overlap period.

In the internal combustion engine **50**, the exhaust valve **55** is closed in the exhaust stroke. As a result, the gas in the combustion chamber E is recompressed in the period M, whereby the cylinder pressure is raised. Where the intake valve **54** is thereafter opened, the cylinder pressure drops and changes from a positive pressure to a negative pressure. In this case, the high-temperature high-pressure gas is blown back from the combustion chamber E into the intake port **52***a*. Therefore, the flow speed is reversed.

In the internal combustion engine **50**, the Pfi injection is performed in the valve opening period of the intake valve **54**. More specifically, in the internal combustion engine **50**, the Pfi injection is performed in conformity with the aforementioned back-blowing of the gas. Even more specifically, when the fuel is thus injected in the internal combustion engine **50**, the injection start timing of the Pfi injection is synchronized with the IVO. As a result, in the internal combustion engine **50**, the fuel is injected from the first fuel injection valve **56** against the back-blown gas.

In the internal combustion engine **50**, the Di injection is performed in the valve opening period of the exhaust valve **55**. More specifically, the Di injection in the internal combustion engine **50** is performed in the second half of the expansion stroke. The Di injection in the internal combustion engine **50** may be also performed in the exhaust stroke, for example, as shown by a dot line. The fuel injected by the Di injection makes no contribution to the combustion and is used for afterburning. In the Di injection, at least a minimum injection amount of fuel that can be injected from the second fuel injection valve **57** can be injected.

The main operation effects of the internal combustion engine **50** are explained below. In the internal combustion engine **50**, the predetermined injection I is performed when the bed temperature of the catalyst **22** is lower than the predetermined temperature T. Therefore, in the internal combustion engine **50**, the build-up of deposits in the nozzle of the second fuel injection valve **57** can be prevented or inhibited. At the same time, in the internal combustion engine **50**, the fuel injected from the second fuel injection valve **57** can be also used for raising the bed temperature of the catalyst **22** by afterburning.

Therefore, in the internal combustion engine **50**, the deposit build-up in the nozzle of the second fuel injection valve **57** can be advantageously prevented or inhibited by injecting the fuel rationally from the second fuel injection valve **57** in addition to the first fuel injection valve **56** even when it is desired to inject the first injection amount TAU from the first fuel injection valve **56**. Thus, since it is possible to increase at the same time the bed temperature of the catalyst **22** in the internal combustion engine **50**, the deposit build-up in the nozzle of the second fuel injection valve **57** can be advantageously prevented or inhibited.

More specifically, the internal combustion engine **50** can be configured to perform the predetermined injection I in the predetermined case (A) in which the bed temperature of the catalyst **22** is lower than the predetermined temperature T. Thus, in the predetermined case (A), where the intake valve **54** is opened, the high-temperature high-pressure gas is blown back from the combustion chamber E into the intake port **52***a*, as explained hereinabove with reference to FIG. **5**.

In the predetermined case (A) in which such back-blowing of gas occurs, for example, the injected fuel can be atomized by injecting the fuel from the first fuel injection valve **56**. Therefore, the predetermined case (A) is suitable for injecting the first injection amount TAU from the first fuel injection valve **56**, from among the fuel injection valves **56**, **57**. As a result, the internal combustion engine **50** can specifically and advantageously demonstrate the above-described operation effect, for example, with such a configuration.

The internal combustion engine **50** can be specifically configured such that the first injection amount TAU is injected from the first fuel injection valve **56** in the predetermined injection I. Thus, the internal combustion engine **50** can be specifically configured such that the first injection amount TAU is actually injected from the first fuel injection valve **56**.

The internal combustion engine **50** can be also specifically configured such that the fuel injection start timing of the first fuel injection valve **56** is synchronized with the IVO in the predetermined injection I. Therefore, it is possible to inject the fuel from the first fuel injection valve **56** against the gas blown back from the combustion chamber E into the intake port **52***a*. As a result, the fuel can be advantageously atomized.

Further, in the internal combustion engine **50** of such configurations, the amount of the back-blown gas can be reduced and the nozzle of the first fuel injection valve **56** can be prevented from being easily exposed to the back-blown gas, by dropping the pressure of the back-blown gas using the fuel injection pressure. As a result, the deposit buildup in the nozzle of the first fuel injection valve **56"** can be advantageously prevented or inhibited. Further, in the internal combustion engine **50** of such configuration, controllability of the air-fuel ratio can be also increased because the prevention or inhibition of injected fuel deposition on the wall surface of the intake port **52***a* is coupled with fuel atomization. As a result, combustion stability in the case of fuel injection from the first fuel injection valve **56** can be ensured.

The internal combustion engine **50** can be specifically configured such that the second injection amount Q is injected from the second fuel injection valve **57** in the predetermined injection I and the second injection amount Q is changed according to the bed temperature of the catalyst **22**. As a result, the exhaust emission can be advantageously reduced by raising the bed temperature of the catalyst **22** while optimizing the injection amount.

The predetermined case (A) may be, for example, the case in which the first injection amount TAU is less than the sum total of minimum injection amounts that can be injected by the fuel injection valves **56** and **57**. This case is also suitable for injecting the first injection amount TAU from the first fuel injection valve **56**, from among the fuel injection valves **56** and **57**. Therefore, the internal combustion engine **50** can also advantageously demonstrate the operation effect also in this case.

The examples of the invention are described in detail hereinabove, but the invention is not limited to those specific examples, and various changes and modifications can be made without departing from the scope of the invention set forth in the claims.

What is claimed is:

1. An internal combustion engine comprising:

a first injection unit injecting fuel into an intake passage communicating with a combustion chamber;

a second injection unit injecting fuel into the combustion chamber;

an intake valve and an exhaust valve arranged with respect to the combustion chamber; and

a control unit performing a predetermined injection such that when a bed temperature of a catalyst for purifying exhaust gas discharged from the combustion chamber is lower than a predetermined temperature, fuel is injected from the first injection unit, from among the first and second injection units, during a valve opening period of the intake valve, and fuel is injected from the second injection unit, from among the first and second injection units, during a valve opening period of the exhaust valve.

2. The internal combustion engine according to claim **1**, comprising

a piston adjacent to the combustion chamber, and a valve train changing at least a valve closing timing of the exhaust valve, from among valve characteristics of the intake valve and the exhaust valve, wherein

the control unit performs the predetermined injection in a predetermined case and in a case in which the bed temperature of the catalyst is lower than a predetermined temperature, and

the predetermined case is a case in which the valve train is in a state of closing the exhaust valve on an advance side with respect to an exhaust top dead center of the piston and forming a minus overlap between the intake valve and the exhaust valve.

3. The internal combustion engine according to claim **1**, wherein

the control unit sets a fuel amount to be injected by the first injection unit as an injection amount required per cylinder.

4. The internal combustion engine according to claim **1**, wherein

the control unit changes a fuel amount to be injected from the second injection unit, according to the bed temperature of the catalyst.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 9,316,171 B2
APPLICATION NO. : 14/244434
DATED : April 19, 2016
INVENTOR(S) : Yuuichi Katou et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

In Column 10, Claim 1, Line 21, delete “control unit performing” and insert --control unit configured to perform--, therefor.

In Column 10, Claim 2, Line 36, delete “control unit performs” and insert --control unit is configured to perform--, therefor.

In Column 10, Claim 3, Line 47, delete “control unit sets” and insert --control unit is configured to set--, therefor.

In Column 10, Claim 4, Line 52, delete “control unit changes” and insert --control unit is configured to change--, therefor.

Signed and Sealed this
Twenty-first Day of June, 2016

Michelle K. Lee

Michelle K. Lee
Director of the United States Patent and Trademark Office